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WHY ALPHABETIC KEYBOARDS ARE NOT EASY TO USE: KEYBOARD LAYOUT DOESN'T MUCH MATTER

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Abstract

It is well known that the Sholes or "qwerty" keyboard is deficient in design, hard to learn, and awkward to use. Many improvements have been suggested. Alphabetically organized keyboards would appear to be superior for novice typists, but this has not been demonstrated in previous studies of typing. The Dvorak keyboard has been promoted as superior for experts, but many studies show only a small improvement, not enough to warrant changing.

In these experiments we confirm the lack of virtue for alphabetically organized keyboards over both a randomly organized one and over the standard Sholes keyboard. More important, we show why. To take advantage of the alphabetic keyboard requires considerable mental processing on the part of the user, and this processing is neither easy to do nor does it appear to offer much savings over visual search of the keyboard. Simple visual search of the keyboard fails to take advantage of the alphabetical arrangement, but is relatively easy to perform. The novice is faced with a tradeoff between mental processing and visual search, and this tends to make different keyboard layouts equivalent. In addition, many people know at least something about the Sholes keyboard, and even this little knowledge is useful, with the result that their performance will usually be better on Sholes than on alphabetic keyboards (and certainly no worse).

Comparison of different keyboard layouts by a computer simulation of expert typing shows suprisingly little effect of keyboard arrangement for a wide class of keyboards. Some alphabetical layouts are quite slow, but others are within 2% of the speed of the Sholes keyboard. The fastest layout is Dvorak, but the improvement is only around 5% over Sholes. So for experts, keyboard layout doesn't seem to matter much. The conclusion is that it is not worthwhile to use alphabetic keyboards for novice typists, nor to change to the Dvorak layout for experts. Keyboards can probably be improved, but only though radical redesign of the present physical key configuration.

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Why Alphabetic Keyboards Are Not Easy to Use: Keyboard Layout Doesn't Much Matter

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These experiments were performed by the second author as a senior honors thesis under the supervision of the first author. The studies were initiated as a result of our frequent discussions with Stu Card and Tom Moran of the Xerox Palo Alto Research Center. We thank them for their valuable suggestions. The research reported here was conducted under Contract N00014-79-C-0323, NR 157-437 with the Personnel and Training Research Programs of the Office of Naval Research, and was sponsored by the Office of Naval Research and the Air Force Office of Scientific Research.

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It seems obvious that the traditional typewriter keyboard -- the "qwerty" or Sholes" keyboard -- presents many difficulties for non-expert typists. The arrangement of the letters on the keyboard seems arbitrary and difficult to learn. There appears to be no system to the layout, and beginners often ask why the keys cannot be laid out in alphabetical order. [1] Indeed, a number of typewriter-like devices do arrange the keys in alphabetical order, including children's electronic toys (e.g., Texas Instruments' "Speak and Spell"), hand-held language translators, note-taking devices, and at least one model of a commercial badge-making machine.

Although an alphabetical arrangement might be best for novices, different considerations are relevant for expert typists. Here, one wishes to lay out the keys so as to maximize typing rate. One major redesign of the keyboard is known as the "Dvorak keyboard." This is a keyboard arrangement based upon human factors (time and motion study) principles that emphasizes an efficient layout of the keys to minimize hand and finger motion (Dvorak, 1942; Dvorak, Merrick, Dealey, & Ford, 1936). Proponents of the Dvorak keyboard have frequently demonstrated advantages in learning time and typing speed, but to little avail against the established dominance of the Sholes arrangement. The question to be examined here is, how big a difference does keyboard layout make for novice and expert.

Possible Advantages of Alphabetic Keyboards

Alphabetical ordering of the keys makes logical sense, and early keyboards were indeed alphabetical. The qwerty arrangement was invented to minimize jamming of keys, but jamming is not a major concern with modern type bars and typing balls, electric typewriters and computer terminals. An alphabetical arrangements would make sense to inexperienced typists, who today must spend considerable time learning the arbitrary arrangement of the Sholes keyboard. Perhaps the strongest argument against any proposed change is simply that the Sholes keyboard is so well known and used that it would not be practical to change. The argument is persuasive enough to have defeated attempts to implement the Dvorak keyboard. The strongest argument for alphabetically arranged keyboards applies to the performance of the novice typist. Both the Sholes and Dvorak keyboards seem arbitrary, and for the novice, there appears to be no reason for the location of the letters on the keyboard. Even the arrangement of keys is peculiar, with several rows of diagonally structured keys that are not well designed for the structure of

---

1. The keys were organized by the Sholes brothers in 1873 to minimize the jamming of typebars in their early design of a typewriter. They placed the keys that were typed successively as far apart on the keyboard as possible so that the type bars would approach each other at a relatively sharp angle, thus minimizing the chance of jamming. Ease of learning or typing were not considered; another triumph of technology over human factors (see Beeching, 1974).

the hands, and shift and RETURN keys located in ways that make typing awkward. Many people have experimented with other schemes (Alden, Daniels, & Kanarick, 1972; Litterick, 1981), but major change seems unlikely, except for specialized application. But if the physical structure of the keyboard is taken as given, still, why not arrange the keys into a structured format so that the novice can find them?

Is the alphabetical arrangement of keys superior for novices? It seems obvious that the answer must be yes: how could it be otherwise? Surely, knowledge of the alphabet will aid in finding the keys on the keyboard, thus enhancing typing speed and reducing mental workload for the novice. However, studies of alphabetic keyboards fail to support this view; novice typists type as rapidly on the Sholes keyboard as on alphabetically organized keyboards (Hirsch, 1970; Michaels, 1971; also see the review by Alden, Daniels & Kanarick, 1972). These studies seem to contradict common sense. Most people believe that the alphabetic arrangement of keys should be superior, at least for novices. Why then have previous studies not shown the superiority? One possible answer is that alphabetic keyboards have been compared with the Sholes keyboards. It is difficult to find people who have not had some exposure to the qwerty keyboard arrangement, and so it is possible that the results were biased by past experience. This opinion was buttressed when one of us (DAN) watched operators of a plastic card-making machine type plastic namecards at the opening hours of a design engineering conference (the machine was the Farrington "Cardwriter II"). The typists had considerable difficulty with the alphabetically arranged keys. When asked how they liked the machines, they responded "horrible" and "I can't understand it." When asked about the keyboards, they said "I can't find the keys," and "I suppose it would be OK if you had time to learn where they were." It would seem that they were not much helped by the alphabetical arrangement, and that for those who knew anything about typing (with the Sholes keyboard), this knowledge was interfering. If knowledge of the Sholes keyboard interferes with the use of alphabetic ones, then this means that in a study of keyboards, the proper control would be to use a randomly organized keyboard, for to the novice, random and Sholes must both look equally plausible, yet they could not have had any experience with the random one. Accordingly, we set out to retest the differences among keyboards, using a randomly structured keyboard as our control. But before we started the experiments, we did some brief observations of keyboards. The first question to ask is, how can the alphabetical arrangement help?

How Can an Alphabetic Keyboard Help?

We were surprised to discover that when we made up alphabetic keyboards and watched ourselves and colleagues type on them, the alphabetic arrangement of the keys did not appear to help. Everyone agreed that alphabetical arrangement seemed more rational, but they did not seem able to use the alphabet in their typing. You can discover this for yourself simply by attempting to type a line of text on each of the keyboards shown in Figure 1 (type by pointing at the appropriate locations with the index finger).

A: The Sholes (qwerty) keyboard

q w e r t y u i o p
a s d f g h j k l ;
z x c v b n m , .
space-bar

B: The "horizontal" alphabetic keyboard

a b c d e f g h i j
k l m n o p q r s
t u v w x y z
space-bar

C: The "diagonal" alphabetic keyboard

a d g j m p s v y
b e h k n q t w z
c f i l o r u x
space-bar

A: The random keyboard

c y i f m g z d n j
q o x h b t r w l
v a u p k e s
space-bar

Figure 1. The keyboard arrangements used in these studies. A shows the standard Sholes or qwerty keyboard. B shows the "horizontal" alphabetic keyboard, C the "diagonal" alphabetic keyboard, and D the random keyboard.

The alphabetically ordered keyboard helps only inasmuch as there is a correlation between letter position in the alphabet and key placement on the typewriter. Part B of Figure 1 shows a reasonably standard alphabetic layout. Notice that the point where the letters shift from one row to another is dictated by the physical arrangement of the keyboard and not by any logical structure of the alphabet. Suppose that you are typing the word flower. The f is located on the third row, near the middle of the keyboard; where should you look for the l? Knowledge of the alphabetic indicates that the l is after the f, and so perhaps you should look to the right to find it. But whether or not this is true depends upon where the linear string of the alphabetic is broken to fit it on the keyboard. In fact, on this keyboard you must look to the left to find the l. Knowledge of the alphabet does not correspond to knowledge of key location. Thus, a simple analysis of the alphabetic layout indicates that maybe the alphabetical arrangement is not so useful after all.

Now consider the arrangement shown in Figure 1 C. This "diagonal" arrangement of the letters allows position in the alphabetic to guide placement of the keys. In the word flower, l occurs both later than f in the alphabet and to the right of it on the keyboard. The correlation between the position of the letter in the alphabet and the location of the key is considerably higher for the diagonally organized alphabetic keyboard than for the horizontally organized keyboard. This keyboard arrangement should therefore be better than the horizontal arrangement. However, our informal observations didn't support this outcome either.

How could the alphabet be of use, even for the diagonal keyboard? To be useful, a considerable amount of mental computation is required. Here is a basic algorithm for alphabetic search.

The alphabetic search algorithm:

A1. Call the letter just typed the "current letter" and its keyboard location the "current location";

A2. Determine the next letter to be typed from the text;

A3. Mentally determine the position in the alphabet of the letter to be typed relative to that of the current letter;

A4. Mentally translate the relative alphabetic position to a keyboard location; call the new keyboard location the "target location" (TL);

A5. Do a saccadic eye movement from the current location to TL;

A6. If the letter to be typed is at TL or in view, move the finger to the location and type the key, otherwise call the letter at TL the "current letter" and its keyboard location the "current location" and repeat from step A3.

Obviously, there is more to the use of an alphabetically organized keyboard than is obvious at first analysis. Compare how a person might type on a random keyboard. The algorithm is based on visual search, and is much simpler.

The visual search algorithm:

R1. Call the letter just typed the "current letter" and its keyboard location the "current location";

R2. Determine the next letter to be typed from the text;

R3. Do a saccadic eye movement from the current location to a new target location. (Many possible search strategies could be used to determine the new target location, and the resulting movement could be random, linear-horizontal, etc.);

R4. If the letter to be typed is at the target location (TL) or in view, move the finger to the location and type the key, otherwise call the letter at TL the "current letter" and its keyboard location the "current location" and repeat from step R3.

A major difference between the two algorithms is the amount of mental computation; Steps A3 and A4 for the alphabetical keyboard have no counterpart with the random keyboard. This means that there is a considerable amount of mental effort expended in the case of the alphabetic algorithm, almost none in the visual search algorithm. In addtion, the alphabetical algorithm requires that typists be able to use information about the relative location of letters in the alphabet, but several studies have shown that peope do not know the relative locations of all pairs of the alphabet, but must compute them by a search of their long term memory knowledge of the alphabet structure (see Hamilton & Sanford, 1978 and Lovelace & Snodgrass, 1971). So, it is now possible to understand why there might not be much aid given by alphabetically arranged keys; there is too much mental computation required, and very little gain. Still, we weren't sure we believed either this analysis or that of the previous experiments, so we did a simple experiment.

Experimental Analysis of Alphabetic Keyboards

Method

Four keyboards were studied (as shown in Figure 1). The Sholes keyboard was a standard computer keyboard that was connected to one of the laboratory computers. The other three keyboards were made by taking three of the older keyboards in the laboratory and moving the key caps to make the desired arrangement. These keyboards were connected to a set of lights (LEDs) that displayed the code of the key being pressed, but they were not otherwise operational. (These keyboards were leftover from a previous generation of discrete transistor circuits and were not

easily interfaced with the voltage levels now in use in the laboratory.) All keyboards were mounted in a sloping panel of relatively standard dimensions, height, and angle, and the three non-qwerty keyboards were identical except for the arrangement of their keycaps.

The interkeystroke intervals for the Sholes keyboard were recorded by the computer. Because the other keyboards could not be connected to our system, we videotaped the hand and eye positions, using a counter that electronically put a number on each video frame. The video tape was analyzed with a Sony stop-action recorder and video disc, allowing for reasonably rough determination of keystroke intervals (to within 1/60 second). (The times could be determined by coding the frame at which the LEDs went on that specified the depression of the key; the LED code gave an unambiguous specification of which key was pressed.)

Subjects. Twelve subjects were studied, all undergraduate students at UCSD who either received course credit for taking part in the experiment or who were paid. The subjects were screened for typing ability and the advertisement requested that only non-typists apply. All subjects were given a pretest on the Sholes keyboard and any who typed over 25 wpm (2.1 letters/second) were dismissed. The average typing speed of the 12 subjects on the Sholes keyboard was 16 wpm (1.3 letters/second).[2]

Design. The subjects were first given a pretest on the Sholes keyboard. They were then were tested for 10 minutes on each of the other three keyboards in counterbalanced order, with a 5 minute rest between tests. (With three keyboards and 12 subjects, this yielded two replications of each order.) The same text was used throughout; we opted for consistency of the letter strings in the experimental material at the cost of some learning of the materials, counting on the counterbalancing to even out the factors. The text was adapted from a Reader's Digest article on diets.[3] It was approximately 12,000 characters long and was presented as double-spaced, typewritten copy, printed in all upper case characters. The design of the keyboard was explained to each subject prior to each trial. The instructions stressed speed with accuracy. Subjects typed as much of the text as they could within the 10 minutes allowed them. After all the trials had been completed, we asked the subjects for their subjective impressions and preferences.

Experimental Results and Discussion

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2. The speed criterion (25 wpm) is is the same as used by Hirsch (1970). The mean typing rate of his "non-typists" was 0.9 letters/second, compared to our value of 1.3.

3. The text was prepared by Donald Gentner for use in other typing studies in our laboratory (Gentner, 1981).

The number of letters typed by each subject during each ten minute session, excluding punctuation and spaces, are presented in Table 1. The keypresses were determined by viewing the videotapes and noting the LED indicators activated by the keyboards (the keyboards produced neither hard copy output nor computer-readable output). Note that subjects did not type very much in each 10 minute session; most subjects only managed to complete 60 to 100 words with the alphabetic and random keyboards. Most errors were substitutions of words similar in sounds or meanings to the target words. Errors also included skipped words. Thus, most typing errors were perceptual or memorial in nature, not keyboard typing errors. (Typing rates are usually computed by dividing the number of letters typed per minute by five, the standard conversion between letters and words. Spaces are typed with relative ease, and do not differ across keyboards. Thus, by not counting the typing of spaces, we amplify any possible differences among keyboards. When qwerty typing speeds are computed including the spaces, the mean speed increases from the 13 wpm shown in Table 1 to 16 wpm.)

An analysis of variance performed on the non-qwerty keyboards showed a significant effect of keyboard type ($F = 6.235$, $p < .01$). A 95% Sheffe confidence interval on the data (with order used as a covariate) showed any difference of 29 key presses to be reliable. Thus, there is a small (10%) but significant superiority of the two alphabetical keyboards over the random one, but no difference between the two alphabetic types. The times for the qwerty keyboard are included for comparison purposes; they are clearly superior. (The qwerty keyboards were not tested within the same experimental design as the others and so cannot be included within the ANOVA. However, for 11 of the 12 subjects, the qwerty speeds exceed that of all the other keyboards.)

Learning rate.

It is possible that the learning of the alphabetical keyboard could proceed more quickly than that of the random or qwerty keyboard, for the structure of the keyboard would help in the learning of key placement. Two factors indicate that this is not likely to be the case. First, the thing to be remembered is which finger types which keys, and this is not helped much by horizontally organized alphabetic keyboards (e.g., the middle finger of the left hand types c, m, and v; the alphabetic nature of the keyboard arrangement is not apparent). Second, the studies of Hirsch (1970) and Michaels (1971) showed no superiority in learning rates. To asses differences in learning, we compared the number of keypresses typed by each subject in the first half of each session with the number typed in the second half. In general, subjects did improve in the second half. However, the improvements were small; the differences in keystrokes between the second half and the first half was 18, 19, and 25 for the horizontal, diagonal, and the random keyboards, respectively. Moreover, the standard deviations were relatively large: 15, 21, and 18, respectively. Thus, there appears to be no differences between the learning rates of the two alphabetical arrangements, and the learning of the random keyboard is greater than that of the alphabetic, contrary to expectations. However, it is also the case that typing rate

Table 1

Letters typed in 10 minutes
(not including spaces and punctuation)

Subject	KEYBOARDS				Order of keyboard presentation
	Qwerty	Horiz. (alphabetic)	Diag.	Rand.	
1	505	292	302	362	q h d r
2	815	395	367	346	q r h d
3	295	384	340	313	q d r h
4	605	411	453	323	q h r d
5	405	331	354	292	q d h r
6	740	412	416	364	q r d h
7	705	330	330	364	q h d r
8	630	426	432	329	q r h d
9	870	400	349	374	q d r h
10	740	458	524	457	q h r d
11	700	351	336	306	q d h r
12	770	462	474	415	q r d h
Mean:	648	388	373	357	
Letters/sec.	1.08	0.65	0.62	0.60	
Words/min.	13.0	7.8	7.5	7.1	

on the random keyboard was slower, so perhaps the greater learning rate reflects the fact that the subjects have more to learn.

Subjective preferences. Subjective preferences for keyboards varied. Three subjects said that they preferred the random board. Six said that they preferred the alphabetic boards, and three said they did not find much difference among the three. When asked to compare the two forms of alphabetic keyboards, two subjects said they had no preferences, five preferred the horizontal, and two preferred the diagonal. Two subjects said that the alphabetic keyboards were frustrating, while two subjects said that the random board took more concentration. One subject commented that while he performed better on the alphabetical keyboards, he would have preferred the random if he had a chance to get used to it. In general, the subjective preferences do not appear to be useful. We did not expect this result; we believed that the subjects would prefer the alphabetically organized keyboards, even if their performance did not warrant it. Unfortunately, we got the preference rating last, after subjects had used all keyboards. Perhaps their natural preferences were changed after they had 10 minutes of frustration is attempting to use the keyboards.

To test the influence of experience on subjective impressions, we selected new subjects in the same manner as we had selected the first 12. This group was asked to give their subjective impressions of three keyboards; qwerty and the two alphabetical arrangements. In addtion, their typing speed on the qwerty keyboard was measured. [4] The subjects were shown a picture of each keyboard, without being allowed any experience with them. Unfortunately, there was still no difference in preference. Even when we looked at the slowest (poorest) typists in the group, no differences emerged. Thus, the subjective ratings of the 11 slowest subjects whose qwerty typing rate was measured by us to be less than 20 wpm on a seven point rating scale (with 7 meaning "like very much"), is 4.2, 4.6, and 3.2 for the qwerty, horizontal, and diagonal keyboards, respectively. (The standard deviations are 1.4, 1.8, amd 1.3, and the mean qwerty typing speed is 15.5 wpm.) The small difference in preference between the qwerty and the alphabetic keyboards is clearly not significant, and the diagonal keyboard is the least preferred.

Conclusion. The appropriate assesment of alphabetic keyboards is made by comparing their performance with the random keyboard, thus avoiding contamination with the qwerty arrangement. Any negative influence of prior knowledge of the qwerty keyboard should have equal influence on both the alphabetic and the random keyboards. There is a slight advantage of the alphabetically organized keyboards over a randomly organized one. This advantage is around 10%, a difference of slightly less than one word per minute. The advantage may be statistically significant, but it is of no practical significance.

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4. Phil Mercurio performed this experiment and collected the ratings.

It is unfortunate that we got subjects with knowledge of the standard keyboard, even though we attempted to get people with no typing experience. It is difficult to find people who have not had experience with typewriters, and this is especially true in a college environment. Note that Hirsch (1970) found essentially the same amount of knowledge with his "non-typists." Nonetheless, the lack of meaningful difference between the alphabetic and the random keyboards is striking. Note that our subjects were clearly superior on the qwerty keyboards. Even though they could only type about one letter per second, the qwerty keyboard yielded a 67% improvement over the speed reached with the alphabetic keyboards and an 83% improvement over the random keyboard.

The Effect of Keyboard Arrangement on Experts

What would happen with expert typists? How would they be affected by different keyboard arrangements? We despaired of doing the actual experiments because to do so would require months of training on a variety of keyboards to get people to expert status, and then a considerable amount of retraining of the subjects so that they were back to normal on regular typewriters. The experiment has actually been done with the Dvorak keyboard. Estimates vary, ranging from a 5 to 10% improvement in typing speed to no significant difference (Alden, et al., 1972).

It is possible to compute the effects of keyboard arrangement on typing speed. Kinkead (1975) devised a computational method based on the keystroke intervals for typing keystroke patterns, the relative frequency of English digraphs, and the physical arrangement of the keys. He estimated only a 2.6% improvement in typing speed with the Dvorak layout, although he thought it possible to devise other keyboard arrangements that could give a 7.6% improvement. That size improvement, he concluded, "would probably be lost in the flurry of re-training and re-building 20 million typists/machines."

Card, Moran, and Newell (1981) have extended Kinkead's analyses to cover other arrangements of keys (they have also generalized and simplified the analytical methods). They find that the Sholes keyboard falls in the middle of a range of possible speeds, with the Dvorak arrangement yielding a maximum improvement of 11% and certain inelegant alphabetic arrangements yielding a decrement of about 10%. (Card & Moran, personal communication).

Rumelhart and Norman (1982) have developed a computer simulation of the hand and finger movements of a skilled typist. With this program, it is possible to estimate the effects of any keyboard layout, including ones in which the keys are physically quite different from that of the standard typewriter (the Kinkead and Card, Moran, & Newell techniques are tied to the standard typewriter by the use of empirical time estimates based on the qwerty layout). This simulation includes the cognitive and motor control mechanisms, and the output is a computer graphics display of the hands and fingers moving over the keyboard, plus the reaction time distributions of interkeypress intervals.

Using this simulation model, we have tested a variety of keyboard layouts. The typing program was run with different keyboard layouts, using the same text as we used in our experiment. The typing model yields reaction time distributions for the interkeystroke intervals in arbitrary model units, and these were transformed into words per minute by assuming that each model unit was 40 milliseconds. This yields a reasonable typing rate for an average, secretarial level typist (about 55 wpm). In computing the typing speeds, carriage returns were not counted, but spaces and simple punctuation were used (periods and commas). The text was in all upper case, and so no shift key operations were required. The data from the simulations are shown in Table 2. Despite the very different assumptions and mechanisms of the typing model from the other methods, our estimates agree with the work of Card and Moran within the accuracy of the estimations; about a 5% improvement for Dvorak, and a decrement for the horizontal alphabetic keyboards that ranges from 2% to 9%, dependent upon the particular layout that is used.

Different layouts of keyboards produce considerably different loadings of the two hands, as well as different percentages of keypresses required off the home row. Detailed studies of the timing characteristics of typing have shown that between-hand letter digraphs are typed faster than within-hand, and between-finger digraphs faster than within-finger (Gentner, 1981; Kinkead, 1975; Rumelhart & Norman, 1982). These and other factors indicate that for optimum typing speed, keyboards should be designed so that:

A: The loads on the right and left hands should be equalized;

B: The load on the home (middle) row should be maximized;

C: The frequency of alternating hand sequences should be maximized and the frequency of same finger typing should be minimized.

The Dvorak keyboard does a good job on these variables, especially A and B; 67% of the typing is done on the home row and the left-right hand balance is 47-53%. Although the Sholes (qwerty) keyboard fails at conditions A and B (most typing is done on the top row and the balance between the two hands is 57-43%), the policy to put successively typed keys as far apart as possible favors factor C, thus leading to relatively rapid typing. Thus, the Sholes keyboard actually seems to be a sensible design, superior to all of the alphabetical arrangements that we have studied, and only 5 to 10% slower than the Dvorak keyboard, the one that was based upon time-and-motion studies.

For the expert typist, the layout of keys makes suprisingly little difference. There seems no reason to chose Sholes, Dvorak, or alphabetically organized keyboards over one another on the basis of typing speed. It is possible to make a bad keyboard layout, however, and two of the arrangements that we studied can be ruled out. Note that one of the slower keyboards is "alphabetic 1," or "horizontal alphabetical" in

Table 2

Typing Speeds Calculated from the Rumelhart & Norman Typing Model*
(Words per minute assume each model time unit is 40 msec.)

keyboard	% use (rows)	% left hand	% right hand	model wpm	% deviation from qwerty
QWERTY:					
qwert yuiop	42%	57%	43%	56	—
asdfg hjkl;	27%				
zxcvb nm,.	15%				
-space-	16%				
DVORAK:					
?,.py fgcrl	21%	47%	53%	58	+5.4%
aoeui dhtns	56%				
'qjkx bmwv	7%				
-space-	16%				
ALPHABETICAL-1:					
abcde fghij	37%	64%	36%	52	-7.1%
klmno pqrs;	30%				
tuvwx yz,.	17%				
-space-	16%				
ALPHABETICAL-2:					
;.,ab cdefg	29%	54%	46%	55	-1.8%
hijkl mnopq	29%				
rstuv wxyz	24%				
-space-	16%				
ALPHABETICAL-3:					
abcde pqrst	43%	66%	34%	51	-8.9%
fghij uvwx;	18%				
klmno yz,.	23%				
-space-	16%				
ALPHABETICAL-4:					
abcde fghij	37%	57%	43%	55	-1.8%
klmno pqrst	38%				
,.;uv wxyz	9%				
-space-	16%				
DIAGONAL:					
adgjm psvy;	23%	55%	45%	55	-1.8%
behkn qtwz,	29%				
cfilo rux.	32%				
-space-	16%				

* In these computations, the space key is assumed to be typed with the right thumb.

our experiment. This configuration of keys matches well what people think of when considering alphabetical arrangements. It is not very good at all.

Conclusion

In these studies we have analyzed the novice and expert use of different keyboards. First consider the implications of keyboard layout for novices. We conclude that in order for novices to make use of the alphabetical organization of the keys on the keyboard, considerable workload is involved. Our experimental studies of typing rate show that alphabetically organized keyboards are slightly superior to a randomly organized one, for beginners, but that difference is too slight to be of any practical significance. Moreover, because even a slight knowledge of the qwerty arrangement is apt to help considerably when using the Sholes keyboard (and to interfere with the alphabetical one). We believe that, on the whole, our subjects did not use the alphabetic algorithm, but instead resorted primarily to visual search of the keyboard, thus treating the key arrangement as if it were unstructured: (random). As the comparison of the two different algorithms we presented earlier indicates, this reduces the mental workload considerably, with little effect on performance. There is no sense in introducing the alphabetical keyboard; essentially no one will be helped, yet many will be hindered.

The Sholes keyboard may be easier to learn and to use than a random keyboard. The home row is in quasi-alphabetical order (see Figure 1 A: "...d f g h j k l..."). Hirsch describes its virtues this way:

> "... although not a perfect arrangement, the key arrangement of the standard typewriter is also not a random one. Whatever its limitations, it was 'human engineered' even as early as 1873, and many of the most frequently used letters are, generally speaking, clustered in the center of the keyboard. Hence, hunting for a letter can usually be confined to a relatively small visual area" (Hirsch, 1981, p. 139).

Now consider the implications for expert typists. Our simulation studies of different keyboard arrangements for expert typists depends upon the accuracy of the simulation program. However, in our detailed examination of the simulation model for the Sholes keyboard, it seemed to provide an accurate simulation of many of the properties of the reaction time distributions of skilled typists (Rumelhart & Norman, 1982). In addition, the results presented here for the comparison of different keyboards agree reasonably well with other methods of computation and with experiments comparing Dvorak and Sholes keyboards. These results, therefore, seem reasonable, if only because they are consistent with other methods.

Finally, our analysis of the operations a novice typist would have to perform in order to take advantage of the alphabetical arrangement of keys provides a possible explanation for the lack of improvement with the introduction of these keyboards; the mental load required to make use of the keyboard is too great. (And it is not clear that most people know the alphabet well enough to take full advantage of the ordering.) In his recent review of studies of alphabetical keyboards Hirsch also suggests that this may be the case:

> "... the alphabetical keyboard probably requires, first, a memory search to locate the letter in its approximate or relative alphabetical position, and then a visual search to find the key on the board (where it is situated without regard to its frequency of its use). Accordingly, the combination of the memory plus visual searches may be less efficient than a purely visual search where the probability is high that the visual area first scanned will contain the sought-for letter" (Hirsch, 1981, p. 139).

The conclusion is that both experimental results and various forms of computational models agree that it is a waste of time to re-arrange the typewriter layout; there are pitifully few savings to be had. However, this does not mean that typewriter layout cannot be improved. Kinkead (1975) pointed out that considerable savings could be made by either moving the RETURN key or by eliminating its use altogether (with computer assisted text editing). Elimination of the RETURN key gives a minimum of 7% improvement in speed, and "up to 30% when the original copy is not properly formatted." Thus, simple changes to the way that typists use the keyboards can have a large effect, without changing the key layout.

There is considerable room for dramatic revision of typewriter structure (see Litterick, 1981 for a quick review). Thus, there is little justification for the present size of the keyboard, for the staggered arrangement of the keys, and for other aspects of the physical arrangements. The left and right hands should have a mirror image configuration of keys, rather than the continual upper-left to bottom-right diagonal slope of the keys now used. The left and right hand portions of the keyboard could be separated (allowing the manuscript that is being copied to be placed between the hands where it can be seen without twisting the head). The space bar seems wasted opportunity (most skilled typists only use the right thumb to type spaces, and then only use a small section of the bar). Alternatively, the keyboards could be sensitive to both upwards and downward motion, or keyboards could allow (require) typing of several overlapping keys, or simultaneous depressing of several keys (these are called "chord" keyboards), or several keystrokes could be required per letter, thereby allowing one to reduce the number of keys. Gopher and Eilam (1979) have developed a successful

one-hand keyboard for Hebrew using this technique.[5] Our lesson is simply this; do not waste time re-arranging the letter arrangement of the existing standardized keyboard. And when investigating novel typing schemes, take advantage of computational methods in assessing their validity.

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5. Many of these ideas have been tested out in various formal and informal experiments. We have not seen a proper assessment of them, however, comparing typing speeds, error rates, and difficulty of learning. The standard "chord keyboard" has been studied, and although it is indeed very fast (which is why it is used by court recorders), it is not easy for a novice. A review of many of these methods is found in Alden, Daniels, and Kanarick, 1972.

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